left orbital sinuses, and running in the floor of the skull immediately caudad of the pituitary fossa.

I find that this anastomotic trunk is present in *Mustelus antarcticus,* in which species, however, it hardly deserves the name of sinus, being only 1 mm. in diameter in a dog-fish 1 metre long. Its median portion is situated, not in the actual cartilage of the skull-floor, but in the thick perichondrium of the pituitary fossa, where it lies immediately dorsad and caudad of the arterial commissures w (fig. 6, Plate 35) at their point of crossing. Passing laterad on either side it pierces the cartilage of the cranial floor, and finally enters the orbit by an aperture placed just cephalad of the trigeminal foramen, and about 5 mm. caudad of the carotid foramen.

I doubt whether this can be the anastomotic trunk described by Robin (see p. 712), since it is not situated " derrière les orbites," and can hardly be described as " un sinus plus ou moins vaste."

The vessel in question ought to have been shown in the diagram, fig. B (p. 723) as a narrow trunk connecting the orbital sinuses (*orbit. s.*), and should have been referred to in the general account of venous anastomoses on p. 722.

XXV. "On Rigor Mortis in Fish, and its Relation to Putrefaction." By J. C. EWART, M.D., Regius Professor of Natural History, University of Edinburgh. Communicated by J. BURDON SANDERSON, F.R.S. Received June 6, 1887.

1. *The Nature of Rigor Mortis.*

It has been long recognised that rigor varies extremely not only in the time of its appearance, but also in its intensity. It may be well marked and resemble closely a spasm, or so indistinct that it is better compared to a stiffening than to a contraction of the muscles. So much is this the case that it might be convenient to describe rigor as accompanied with contraction in some cases and with stiffening in others. I have often noticed that when rigor comes on immediately after the loss of muscular irritability, it looks extremely like contraction; but when it is postponed for days, by lowering the temperature or otherwise, it more closely resembles coagulation. I am inclined to believe that whether the rigor resembles a contraction or a mere stiffening depends on the condition of the nervous system. If the coagulation of the myosin takes place at or about the same time as the death of the nerves, the rigor will to a certain extent be physiological, and simulate a contraction in the extension of the fins, the bending of the trunk, &c.; whereas if the coagulation only sets in some hours, or it may be days, after the death of the

nerves, the rigor will be purely pathological, and consist of a mere
fixing of the muscles in whatever position they happen to be. Another
important consideration is what determines the time of appearance
and strength of the rigor.   In some instances I have been unable to
detect rigor, in others, it has appeared at ordinary temperatures, a
few minutes after death, while in other cases it appeared from ten to
twenty hours after death.   Again in some cases it is extremely weak
and of short duration, whilst in others it is well marked and pro-
longed.   It may be safely asserted that if all the nerves in a given
muscle were destroyed, that muscle would still pass into rigor.   But
although the rigor would probably set in were all the nervous ele-
ments destroyed, the nervous system has apparently considerable
influence in determining the time of appearance of rigor.   Some
physiologists seem to believe that the rigor comes on when and
only when death has reached the muscles, by travelling in some
cases hurriedly, in others slowly, from the central nervous system
along the motor nerves.   I hope to show that the longer the
central nervous system continues to act, not only will the muscles
sooner die, but the rigor will be the weaker and shorter, though in
some cases from the arching of the trunk and extension of the fins, it
may appear to be otherwise.

Let us suppose that two fish are instantaneously killed, the one
in a vigorous, the other in an exhausted condition.   In the former a
considerable time will elapse before the energy of the muscles is
exhausted, before the explosive material is all used up, while in the
latter the muscles having already expended nearly all their energy
during life, and little or no new productive material having been
formed after death, they will soon die.   Further, in the fish killed in
an active condition, the muscles will give rise to a well-marked lasting
rigor, whilst in the other it will be weak and of short duration.   The
result of artificial exhaustion is the same as that of natural.   If a
rabbit is killed and immediately after death the muscles of one hind
limb exhausted by an interrupted current, rigor sets in in the ex-
hausted limb two to three hours sooner than in the other.   In the
same way, if a fish is tetanised immediately after death, rigor sets in
quicker than in another fish which has escaped stimulation.   But
further, if two fish are killed and the central nervous system at once
destroyed in one, but left intact in the other, rigor will be considerably
later in appearing in the pithed fish.   The explanation possibly may
be that the central nervous system after death tends to exhaust the
latent energy of the muscles by constantly stimulating them into
action; while, on the other hand, when the central nervous system is
destroyed, the muscles are not stimulated into action, and there-
fore their final passage into rigor depends chiefly on the tempera-
ture and other surroundings.

2. *The Ordinary Phenomena of Rigor in Fish.*

The changes which take place before and during rigor will be best illustrated by the following experiments :—

(1.) Physiological Laboratory, Oxford, 4th February, 1887, 3 P.M.—A large active perch (*Perca fluviatilis*) was taken from the tank and laid on the floor of the Laboratory, temperature 48° F. For about twenty minutes the perch at irregular intervals was very active, but the movements gradually diminished, and about thirty-five minutes after it left the water, all movements had ceased and there was no response to mechanical stimulation.   When stimulated at 3.45 by induction shocks, there was no response until the secondary coil indicated 15 cm.* The muscular irritability gradually diminished, and at 5.45 there was only a slight response at the break with the secondary coil at 0 cm.   At 5.50 the lower jaw and gill-covers were nearly rigid, and the irritability had quite gone in the muscles near the root of the tail, the last to survive.   At 6.0 the pectoral and dorsal fins were rigid, and at 6.10 the rigor had extended as far as the pelvic fins. At 6.15 the whole fish had passed into a pronounced rigor, the mouth was open, the gill-covers projected outwards, all the fins were extended, and owing to the shortening of the muscles of the left side, the fish (which was 9 inches in length) was sufficiently curved to form an arc of a circle 30 inches in diameter.   While the muscles remained irritable, they were neutral or amphichroic, but as the rigor extended from before backwards they became distinctly acid.

As soon as the rigor had set in the perch was placed under a bell-jar in a porcelain dish containing sufficient water to keep the skin moist.   At 10 P.M. the rigor was still well marked, but next morning (5th February) at 10 A.M., the rigor had disappeared from the lower jaw, gill-covers, and pectoral fins.   When placed with the convex side looking upwards, the lateral curvature of the trunk soon gave way and at 12 noon the whole fish, except about 3 inches at the tail end, was quite limp.

At 10.30 A.M., the muscles in front of the dorsal fin were neutral, those behind distinctly acid, at 12 noon the muscles of the anterior half were slightly alkaline, those near the root of the tail were still neutral.   Numerous bacteria were found in the layer of muscles lying around the body-cavity, and a few were found in the muscles under the skin in front of the dorsal fin, but no bacteria could be discovered either by direct observation or by cultivation in the muscles near the root of the tail.

On the 6th February putrid odours were discernible, all the

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* A single Daniell was used in the primary coil in the Oxford, and two Smees in the Edinburgh experiments.

muscles were getting soft, and bacteria, plentiful in the muscles around the body-cavity, were extending into the caudal region.

In this case death occurred about 35 minutes after the fish was taken from the water : muscular irritability disappeared and rigor began to appear 2 hours 15 minutes after death, the rigor was completed in 25 minutes after it set in, and it had vanished about 21 hours after death.

(2.) Zoological Laboratory, Edinburgh, 25th March, 10 A.M.—A common eel (*Anguilla vulgaris*) 18 inches in length, was killed by knocking on the head. At 6 P.M. (8 hours after death) the whole trunk responded freely to mechanical stimulation and the heart was still beating. At 10 A.M. of the 26th (24 hours after death) there was only a feeble response to mechanical stimulation, but strong contractions were produced when the electrodes from an induction coil were applied to the skin,—the secondary coil at 15 cm. At 1 P.M. the muscular irritability had slightly diminished in the anterior third, at 6 P.M. it was still less marked, and at 10 A.M. of the 27th (48 hours after death), with the secondary coil at zero, the muscles of the anterior third contracted very slightly. At 12 noon the muscles of the anterior 5 inches gave no response, but those of the middle third still contracted readily, and the muscular irritability increased towards the tail end. Two hours afterwards (*i.e.*, 52 hours after death) the greater portion of the anterior third had become rigid—the rigor beginning in the lower jaw and passing backwards affecting the gill-covers and pectoral fins and then the muscles of the trunk. At 4 P.M. the muscles of the anterior portion of the middle third of the eel no longer responded to electrical stimulation, and at 8 P.M., the anterior half (about 9 inches in length) was rigid while the posterior half still responded when stimulated—the strength of the contractions still increasing from before backwards. The muscles of the rigid half had a distinctly acid reaction, those of the posterior half were neutral or very faintly alkaline—a narrow zone near the centre being amphicroic. The muscles of the anterior third immediately under the skin were neutral and contained no bacteria, but those next the peritoneum had a few bacilli and micrococci, and were alkaline in reaction.

On the morning of the 28th (9 A.M.) the rigor had all but disappeared from the anterior third, the middle third was quite stiff, and the posterior third, except near the tail end, contracted very feebly with the secondary coil at zero.

At 1 P.M. rigor had passed from the anterior half, but the muscles of the posterior third were still irritable. The reaction of the muscles in the anterior third was now slightly alkaline, and they contained a few bacilli and micrococci similar to those found on the previous day in the muscles around the body-cavity. At 5 P.M. only the terminal 3 inches responded when the electrodes were introduced

into the muscles, and the rigor was passing from the remainder of the middle third and making its appearance in the front portion of the posterior third. At 6 P.M. the rigor had all but gone from the middle third, and a weak rigor had set in in the posterior third. At 8 P.M. (82 hours after death) the whole eel was quite limp—the rigor on the posterior third having been weak and of short duration. The alkaline reaction increased from before backwards, to about 3 inches from the tip of the tail, where it was neutral, and bacteria could be detected in the muscles a little beyond the middle half. Next morning (29th March) all the muscles were alkaline, and a few bacteria were present even in the muscles near the tail end, and the anterior portion was smelling slightly. This eel was under observation until the 13th April, when putrefaction had considerably advanced. While under observation the eel was kept in water which varied from 48—52° F. I may add that the blood and peritoneal fluid were examined immediately after death, and that though small bacilli were fairly abundant in the lymph, it was impossible to discover any organisms in the blood. In this eel the muscular irritability lasted in some of the muscles for nearly eighty-two hours after death. As a contrast to this above experiment, I may describe shortly another.

(3.) On the 6th April, an eel, also about 18 inches in length, which was killed by an electrical shock from a Holtz machine, passed immediately into rigor—what might be called " cataleptic rigor." The posterior half—in which there is no body-cavity—was sterilised (by placing it for a short time in a 5 per cent. solution of phenol) and then introduced with the usual antiseptic precautions into a jar of sterilised distilled water. The rigor still (June 16th) continues on this portion (the posterior half) of the eel, while the anterior half, which was introduced into a 5 per cent. solution of phenol *after the rigor had disappeared,* is now quite limp and soft.

From these experiments it may be inferred that under ordinary conditions there is an intimate relation between loss of irritability and the setting in of rigor, and that rigor vanishes as the bacteria invade the tissues.

3. *The Time at which Rigor appears.*

Under ordinary circumstances the setting in of rigor in the various kinds of fish seems to depend on the amount of irritability of the muscles at death. In all probability it might be possible to discover when the rigor would come on by determining the amount of free acid in the muscles; in other words, there is a relation between the appearance of the rigor and the amount of catabolic material in the muscles at death. This seems to vary in an unaccountable way ; *e.g.,* if three two-year-old trout of as nearly as

possible the same size, which have been living under as nearly as possible identical conditions since the day of hatching, are captured at the same moment while lying quietly in the corner of a tank, and allowed to die in the landing net, the rigor may appear in one (A) 15 minutes after death, in another (B) 30 minutes, and in the third (C) 40 minutes after death. We must suppose that this variation results either from the condition of the muscles at death, or from the influence of the nervous system.

If at death the muscles of (C) contained (owing to the oxygenation of the blood continuing longer) less bye-products than (A), it might be possible to understand why the time at which the rigor set in differed. Again, if in (A) the nervous system continued to produce muscular contractions longer than in (C), *i.e.*, led to the more complete exhaustion of the muscles of (A) than (C), the difference might be easily understood. It is of course difficult, if not impossible, to determine which (if either) of these explanations is the correct one, but that they may both have some influence in the result may be inferred from the following facts. (1.) If two trout are taken from the water at the same time, and one is left with its gills freely open in the landing net, while in the other the gills are kept firmly closed by an elastic band, the one with the gill-covers extended will die, it may be 20 minutes before the other,* but will be 30 to 40 minutes later in becoming rigid, the reason apparently being that the closed gill-covers prevent the evaporation from the gill-chamber, and the consequent increase in temperature and loss of function of the gill-filaments. (2.) If two trout are taken from the water at the same time, the one allowed to die in the landing net, while the other is at once killed and pithed, the rigor sets in in the former several hours (4—8) sooner than in the latter, *i.e.*, it is later in appearing in the fish in which the brain has been destroyed.

Although in some cases it is difficult to account for the time at which the rigor sets in, fairly satisfactory explanations can be given in others. It is well known that most fish can live for months without food. In fact fish in confinement often appear to "thrive" best when not fed, they are less sensitive and less liable to suffer from disease. Even in a wild state fish seem to all but give up feeding for weeks at a time, more especially during the spawning season, and the chief difference between under-fed and well-fed fish appears to be that in the former there is little or no growth, and the spawning period is delayed or the formation and maturation of the roe and milt are arrested. But although many fish are capable of living for months without food in aquaria, now and then one sickens and dies without any apparent cause.

* This was first pointed out to me by Sir James Maitland, Bart., when visiting the Howieton Fishery.

As in warm-blooded animals which die before maturity is reached
from wasting diseases, the rigor soon appears and as rapidly goes, so
in young fish which have been living in confinement, the rigor is
often weak and evanescent.

For example, a young roach about 6 inches in length, which for
some hours had barely managed to survive was killed, and, though
carefully watched, it was impossible to detect any rigor, and equally
impossible fifteen minutes after death to obtain any response from
electric stimulation with the secondary coil at zero. Again, as in a
" hunted hare " the rigor sets in rapidly and is of short duration, so
it is in a long " played " fish.   On April 14th a trout was chased for
nearly half an hour before it was landed.   About 20 minutes after it
was taken from the water, even although the brain was destroyed
immediately after death, the muscular irritability had disappeared,
and the rigor was complete before 30 minutes had elapsed with the
temperature at 9·5° C.   Under ordinary conditions, if an active two-
year-old trout (*S. levenensis*) about 9 inches in length is taken from
the water and left in the landing net, it usually lies perfectly still,
only giving an occasional wriggle.   During the first few minutes the
breathing movements are performed, but as soon as the fish realises
fully it is out of the water, the mouth and gill-covers are tightly
closed—an instinct which fish display, whereby they better their chance
of surviving until they again perchance reach their native element.
In from 20 to 30 minutes, probably owing to the muscles being ex-
hausted, the mouth is opened and the gill-covers are widely extended,
and in a few minutes later (5—10) the fish dies.   If it dies in about
25 minutes, the muscles will respond to mechanical stimulation
10 minutes after death, and 60 minutes after death all the muscles
will respond freely to electrical stimulation with the secondary coil
at 15 cm.   Gradually the muscles from before backwards lose their
irritability, and $1\frac{1}{2}$ hours after death, though the muscles near the
tail still respond with the secondary coil at 15 cm., the muscles of the
lower jaw will only respond when the indicator is at zero, and
2 hours after death only the muscles of the posterior half of the trunk
retain their irritability.   At $2\frac{1}{2}$ hours after death even the caudal
muscles require the secondary coil at 12 cm.; 10 minutes later at
8 cm., and in 15 to 20 minutes more (about 3 hours after death) only
a faint response is obtained with the secondary coil at zero.   Two
hours after death—before muscular irritability has gone from the
caudal muscles—the muscles of the jaw become rigid and the stiffen-
ing extends backwards, overtaking the gill-covers, the pectoral,
dorsal, and pelvic fins and one myotome after, until the rigor is
complete.

The time required is never the same, but on an average the rigor
is accomplished in a trout allowed to die in a landing net, and

kept afterwards in the air at a temperature of 9° C., in from 1 to
1½ hours—3 to 3½ hours after death. When a trout is taken from the
landing net immediately after all signs of life have gone, and placed
in water at the same temperature (9°C.) the irritability continues
about 10 minutes longer, and the rigor is from 15 to 20 minutes later
in setting in. When the temperature is raised to 15° C. the irrita-
bility goes, and the rigor appears in from 20 to 30 minutes, and
reaches the caudal muscles about 45 minutes after death. At a tem-
perature of 25° C. the rigor may set in in 15 minutes, and be complete
in about 25 minutes after death, while at a temperature of 30° rigor
often comes on in the trout 5 minutes after death, and vanishes 15 or
20 minutes later. At a temperature of 38° C. heat rigor at once sets
in. As the temperature is lowered the rigor is later in making its
appearance, and a considerable period elapses between the loss of mus-
cular irritability and the setting in of rigidity. At low temperatures
it is often extremely difficult to say at what time the stiffening begins.
A trout in water at 1° C. seemed to pass into rigor about 23 hours after
death; at —1° C. there was no distinct rigor 30 hours after death,
but well-marked stiffness 10 hours later, but at lower temperatures
(—7° to —20° C.) neither rigor nor stiffening could be detected in
four trout which had been respectively 2, 3, 4, and 5 days in the
freezing mixture. Further, trout which had been subjected to a tem-
perature below —7° C. never stiffened, even when introduced imme-
diately after thawing into water at a temperature of 25° C.

Judging from the above and other experiments, it seems that
raising the temperature either before or after death has the same
influence as muscular or nervous exhaustion in hastening the rigor.
The increased temperature quickens all the chemical and other
changes, and thus leads to the rapid and all but complete destruction
of the catabolic material stored up in the muscles. On the other
hand, cold either diminishes or arrests the metabolic changes. At a
temperature below freezing point the muscles contract, even when
stimulated less quickly, and hence they long retain almost unaltered
the contraction-producing material which happens to be present when
death sets in; so that when the rigor eventually appears it, as already
mentioned, more resembles a mechanical coagulation of the muscles
than a strong contraction. It is difficult to determine whether the
rigor, which appears at a low temperature (5° to —1° C.), is really
stronger than the rigor that comes on at a high temperature. When
a trout, in which the rigor has set in at a temperature of 2° C., is
placed in water at a temperature of 25° C., stiffening vanishes in
about the same time as it would had the rigor set in at a temperature
of 20° C.

The intensity and duration of the rigor which follows death in
warm-blooded animals from lightning has been again and again

discussed. It is stated by some that rigor never appears, whilst others assert that the rigor which follows death by lightning is often well marked and of considerable duration. From experiments made with fish it seems that in some cases the rigor may be instantaneous and well marked, or it may appear some time after death and be of short duration, whilst in others it may resemble closely the rigor that sets in after death from ordinary causes. When a trout receives a sufficiently strong electric shock it is instantaneously killed, and at the same moment thrown into a well-marked tetanic spasm which passes directly and almost imperceptibly into rigor. A trout about 10 inches in length which received a strong shock* by placing one electrode under the left gill-cover and the other (a chain) round the tail, was thrown into a pronounced spasm which closely resembled a heat rigor; the lower jaw was depressed, the gill-covers widely opened, the fins fully extended, and the trunk strongly arched. After the shock the gill-covers and tail quivered two or three times, and in about five minutes the muscles lost their irritability, and in three minutes more were strongly acid. Ten minutes after the shock the fins became if possible more extended than before; this further extension indicating probably the passage of the tetanic spasm into a true rigor.

In all the experiments when a sufficiently strong current was used the result was the same, but on several occasions, though the current was strong enough to cause death, the muscles recovered from the tetanic spasm, and rigor set in about one hour and twenty minutes afterwards. On other occasions, though the fish was thrown into a strong spasm and seemed dead, there was in from ten to fifteen minutes complete recovery. When fish, which had not only been killed by the shock, but had apparently also passed into a strong rigor, received several additional shocks not later than thirty minutes after the first, the rigor disappeared, and although the muscles failed to recover their irritability, rigor did not again set in for nearly an hour. This seems to confirm what has already been observed by others, that rigor up to a certain limit may be broken down and kept at bay for some time. The breaking down of the rigor may be accounted for by supposing that only a certain proportion of the fibres had stiffened, or that coagulation had been incomplete. It was especially noticed that when the muscles recovered from the first tetanic spasm in fish which had been killed, it was impossible to bring on a second spasm sufficiently strong to pass directly into rigor, and further that the spasm which appeared in fish stimulated after death was never so well marked as in fish which were simply under the influence of ether.

* A Holtz machine was used, and the jar was 8½ inches in diameter with coatings 18 inches high.

Nevertheless, when both the brain and spinal cord had been destroyed, the spasm was sufficiently strong to pass directly into rigor, showing that however much the peripheral nerves were concerned, "cataleptic rigor" was possible without the central nervous system.

It has always been extremely difficult to account for partial cataleptic rigors, such as sometimes occur in the battlefield from gunshot wounds. It has been supposed by Falk and others that these obscure rigors result from injury of the spinal cord. I had no difficulty in producing partial rigors in fish, *e.g.*, when one electrode was introduced into the brain of a fish, and another into the muscles half along the lateral line, the anterior half of the fish was thrown into strong rigor, from which there was no recovery, while the rest of the fish remained quite limp for five hours after death. Before the posterior half of the fish had become stiff, the rigor had all but disappeared from the anterior half ; the posterior half remaining rigid for nearly twelve hours. In the same way, in a fish in which the brain and spinal cord had been destroyed, the posterior half could be thrown into rigor which almost vanished before the anterior half became rigid. Hence we may suppose that in partial rigor a strong tetanic spasm has been produced directly influencing the muscles, or by injury of the nerves or the nerve-centres by which a particular group of muscles is controlled. I may mention that in several instances the electric current was seen to flash along the surface of the skin, and that when this happened there was often marked pigmentation of the one side, while the other remained pale, and further the muscles under the darkened skin were often quite rigid, while those under the unaltered skin remained for a time elastic and extensible.

The influence of Faradaic currents and of often repeated continuous currents was very marked. A trout, *e.g.*, in which after death first the brain and afterwards the spinal cord were stimulated, was thrown into spasms which became weaker and weaker until, 10 minutes after death, no response was obtained. In this case the rigor set in 20 minutes after death, and 20 minutes later it had extended to the caudal muscles. The appearance and nature of the rigor were always directly related to the previous exhaustion produced in the muscles.

The effect of animal electricity seems to correspond to that of ordinary electricity, except that in fish killed by electricity from electric organs the rigor seems later in setting in. For example, in two small roach killed by the electric eel (*Gymnotus electricus*) in the insect house of the Zoological Gardens, London, on the 21st March, and kept under observation in water at a temperature of 45° F., no distinct rigor had set in twelve hours afterwards.* Two roach killed on March 31st about 5 P.M., after receiving numerous weak shocks

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* I am indebted to Mr. Romanes for making this observation.

from the apparently exhausted electric organs, began to stiffen 10 hours afterwards, and were quite rigid $11\frac{1}{2}$ hours afterwards, the temperature varying from 50—44° F. On the 3rd April two other roach were "struck" when the fish was vigorous, one was killed by the first shock, the other after receiving two shocks, and both were quite rigid $5\frac{1}{2}$ hours afterwards. We thus see that the setting in of the rigor is related to the strength of the shock received, but that even when the shock is strong enough to cause instantaneous death the rigor is delayed for several hours.   The advantages of being able to kill the fish instantaneously without producing immediate rigor is evident enough. It would be often uncomfortable if not impossible for Gymnotus (and still more for the small-mouthed torpedo) to swallow a fish in strong rigor, and yet unless the fish were sufficiently "numbed" they would readily escape from their sluggish destroyers. It may be mentioned that a trout which had been pithed immediately after death and placed in artificial gastric juice at a temperature of 100° F., became rigid in less than a minute, and the rigor completely disappeared 35 minutes later. A similar fish in water at the same temperature became at once rigid, but the rigidity persisted for an hour and ten minutes.

Experiments were made to determine the influence of acid, alkaline, and other solutions in bringing on and keeping back rigor. Salt solution, as is well known, prevents rigor setting in in proportion to its coming into contact with the muscles.   Alkaline and septic solutions seem to have no influence either way, while acid and corrosive solutions seem to hasten its appearance, but the latter only to a limited extent.   Generally speaking, whatever tended to influence the rigor influenced the irritability of the muscles, but at low temperatures there was no relation between the disappearance of the irritability and the setting in of the rigor.   The muscles lost beyond recovery their irritability in the trout when the temperature was kept for a few minutes at −70° C., but while this temperature was maintained no rigor appeared, and, as mentioned above, fish which were kept under −70° C. for several days never became rigid when removed from the freezing mixture; in some cases, however, they seemed to become slightly firmer—the continued freezing probably so alters the tissues that the usual coagulation or stiffening is rendered impossible.

4. *The Duration of Rigor.*

There is, as generally believed under ordinary circumstances, a close relation between the duration of a rigor and the time at which it sets in ; *i.e.*, if a rigor sets in half an hour after death, it is not likely to last long, while if it appears twelve hours after death, there is a probability that it will continue for several hours. On the other hand,

there does not seem to be usually an intimate relation between the apparent intensity and the duration, for a short-lived rigor produced at a high temperature may look most pronounced, while a fish in a *strong* rigor (which may last for twenty-four hours or more) has often neither the gill-covers nor fins extended, nor the body distinctly arched. We must suppose that there is some relation between the duration of the rigor and the condition of the muscles when it sets in. If before the rigor appears the latent energy of the muscles has been all but exhausted, either before or after death, naturally or artificially, the rigor though well marked will be of short duration, while on the other hand if a considerable amount of rigor-producing material is left when the stiffening supervenes, the rigor, though not strikingly resembling a tetanic spasm, will be more intense and more persistent.

As the rigor comes on, all the muscles shorten (or contract), the extensors usually overcoming the flexors and the muscles of one side (or probably the red muscles of one side) overcoming the muscles of the other, and thus leading to arching or lateral curvature of the trunk. This curving is sometimes so intense that a fish 10 inches in length may form the arc of a circle little over 6 inches in diameter. Up to a certain time after the rigor sets in it may, either by electrical stimulation or mechanically, be broken down, not once, but several times; but the oftener the coming on of the rigor is interfered with, the final rigor is the weaker and the less persistent. Apparently at ordinary temperatures there is a regular order, not only in the stiffening of the various groups of muscles, but also of the various bundles of the individual muscles. If this is the case, the alternate appearance and disappearance of the rigor may, as already indicated, be accounted for by saying that when a partial rigor is broken down, the stiffening of certain muscles or portions of muscles has been arrested or destroyed, and when the rigor sets in again new muscles or muscular bundles have stiffened, while those in which the rigor had previously appeared either remain limp or have their rigidity completed. When rigor which has been fully established in isolated muscles or groups of muscles is destroyed, it never reappears. I have not yet succeeded in recording in a satisfactory manner the strength of the rigor under different conditions, but from the results already obtained, it appears the more rapidly the rigor comes on the more closely it resembles an ordinary muscle contraction.

A comparative table showing the changes which take place in the muscles of different animals at different temperatures while the rigor is coming on and going off would be very instructive. It may be mentioned that in fish, as in other vertebrates, as the rigor comes on there is a rise in temperature, and the reaction changes often rapidly from slightly alkaline or neutral to distinctly acid. In a

trout about 10 inches in length the temperature during life was
10·15° C., the temperature of the water being 9° C., and the air 9·3° C.
After death the temperature fell to 9·5°, but as soon as the rigor had
set in, the temperature of the muscles rose rapidly, reaching when the
rigor was all but completed 10·3° C.   Ten minutes after the rigor had
been completed the temperature was 10·2°, and it gradually fell until
it reached 9° C., forty-five minutes after the maximum had been
reached.   In this fish rigor began to disappear two hours after death,
and as the rigidity vanished the temperature again rose, being 10° C.
three hours after death, 10·05° when the rigor, four hours after death,
had vanished from the anterior third of the fish, and 10·03° when only
the muscles of the tail continued rigid, when the fish became quite
limp ; six hours after death the temperature was again 9° C.   As
putrefaction proceeded the temperature again rose to 10° C., and it
varied between 9·5° C. and 10° C. for two days, after which it was
the same as the temperature of the laboratory.   The acidity increased
as the rigor came on, and then gradually diminished until the muscles
were neutral.   As putrefaction advanced the tissues became decidedly
alkaline.

The rigor is least persistent in fish which die in an exhausted con-
dition at a high temperature.   If an exhausted trout is placed
immediately after death in water at a temperature of 35° C., rigor
appears in from 3 to 10 minutes and disappears in from 15 to 30
minutes, *i.e.*, at the most 40 minutes after death.

If a trout is killed and pithed and then introduced into water at a
temperature of 35° C., the rigor appears in from 10 to 15 minutes,
and persists from 50 minutes to 1 hour.   In a fish treated in the same
way at a temperature of 25° C., rigor appears in from 60 to 65 minutes,
and persists for $2\frac{1}{2}$ to 3 hours ; while a similar trout placed in water
at 15° C. does not begin to stiffen for 5 hours, and the rigor may only
be completed 7 hours after death, and begin to pass off about 20 hours
after death.   The nervous system has doubtless considerable influence
in determining the length of the rigor, as it has in deciding its time
of setting in.   If an active trout (A) is carefully captured and allowed
to die in the landing-net, which when undisturbed it usually does
without a struggle ; and if when all signs of life in (A) have vanished,
a second trout (B) is secured and at once killed and the brain and
spinal cord destroyed; in (A) the rigor may begin to disappear 2 hours
after it has been completed, and may only last altogether 7 or 8 hours,
while in (B) it may last at least 24 hours.   When the brain only is
destroyed it disappears from 1 to $1\frac{1}{2}$ hours sooner, the temperature
being from 9—10° C.

The difference of the duration of the rigor in fish which are
allowed to die and in fish which are knocked on the head or have both
brain and spinal cord destroyed is well marked at all temperatures above

5° C., but at temperatures below 5° C. the difference is less evident, the cold serving either to paralyse the nervous system or to prevent the muscles responding to the weak stimulations which reach them.

If two fish, one (A) with brain and cord destroyed, the other (B) with both intact (B having been allowed to die slowly in the net), are placed in water at a temperature of 25° C., the rigor in (A) persists for $2\frac{1}{2}$ to 3 hours, while in (B) it vanishes in $1\frac{1}{2}$ to 2 hours. If two similar fish are kept under observation at a temperature of 5° C., in the pithed specimen the rigor may last three days, while in the other it may not last 48 hours. As it is impossible to suppose any vital changes take place after the rigor appears, its duration must depend on the condition the muscles are in when they become rigid, so that we must account for rigor in pithed fish persisting longer than in fish allowed to die naturally, in the same way as we account for rigor setting in at different times in fish differently treated.

There is little to add to what has been already said as to the influence of temperature in driving off or maintaining rigor. In unpithed fish the rigor at a temperature of 35° C. may only last 30 minutes, at 25° C. it may last 5 hours; at 15° C. it may persist for 24 hours; at 10° C. 36 hours; at 5° C. 46 hours; at 1° C. three days. At -2° C. it continues unchanged for an indefinite time. On the other hand, in fish which after the rigor had set in were kept for several days at a temperature between -7° C. and -20° C., the rigor disappeared before the thawing was completed.

Perhaps the rigor was destroyed by alterations produced in the muscular fibres during freezing. It was certainly not owing to the direct contact of the salt and ice freezing mixture, for the same results were obtained when fish were frozen in air, and in fresh water in stoppered bottles. That the rigor persists until the fish are thawed does not seem probable, because it persists for some time after thawing in fish which have been for ten days at -2° C., and true rigor never appears in fish which have been kept for several days below -7° C.

The duration of rigor which occurs after death from an electric shock varies considerably, the variation evidently depending either on the direct influence the charge has had on the muscles or on the condition of the central nervous system after the shock. In a trout which was killed and thrown into instantaneous cataleptic rigor at one and the same moment, the rigor began to disappear from the jaw and gill-covers $7\frac{1}{2}$ hours afterwards, and 16 hours later it had completely passed off. In another trout in which only the anterior half was stimulated, the rigor had passed off 9 hours afterwards, about 3 hours after the rigor appeared in the posterior unstimulated portion. Conversely when the shock was passed through the posterior half of a trout, the rigor continued until $8\frac{1}{2}$ hours after death, while the rigor in the anterior half,

which was completed 6 hours after death, lasted 11 hours, the order of appearance and disappearance in this case being practically reversed.

In a trout, in which one electrode was in contact with the skin while the other was in the water, the fish was thrown into a strong spasm, but not instantaneously killed. The skin of both sides behind the point of contact of the electrode (which was near the head) became deeply pigmented, the jaws and gill-covers continued to move at intervals for 30 minutes, after which there were no signs of life. The tetanic spasm seemed to pass off to a certain extent, but as soon as the gill-covers stopped acting, the muscular irritability was lost, and a strong rigor set in which lasted for nearly 15 hours.

Another trout, which was tetanised and killed by an electric shock, recovered from the spasm and passed into a rigor $2\frac{1}{2}$ hours afterwards, which only lasted 7 hours.

Another trout, which was killed, but not permanently tetanised by the first shock, received seven other shocks, some of them of great intensity. In less than an hour after the first shock rigor set in, but it was of short duration, for in 20 minutes after the stiffening appeared the jaw and gill-covers were relaxed, and the whole fish was soft and limp $1\frac{1}{2}$ hours after death.

It may be taken for granted, from the experiments made, that the prolonged rigor of pithed fish is closely related with the destruction of the central nervous system, but it does not necessarily follow that the strength of the rigor in fish, instantaneously killed and stiffened by an electric shock, has the same explanation. It is doubtless possible that a single strong shock may, by destroying the nervous apparatus, produce the same results as pithing, but it is also possible that the appearance and duration of the rigor in fish killed by electricity may be largely influenced by chemical changes in the muscles.

The observations made as to the appearance and duration of rigor in the trout have been confirmed by control experiments on other fish. It will be sufficient in the meantime, to refer to the behaviour of the perch (*Perca fluviatilis*), roach (*Leuciscus rutilus*), and eel (*Anguilla vulgaris*), under conditions similar to some of those above mentioned.

In a roach, which died in an exhausted condition, there was no response to mechanical stimulation, and 30 minutes after death only a weak response at break, with the secondary coil at 0·0 cm. It was almost impossible to say either when the rigor set in or disappeared, and four hours after death the muscles of the trunk were alkaline, and contained bacteria. A similar roach, which was killed by a blow on the head and afterwards pithed, responded freely to mechanical stimulation for 1 hour and 20 minutes. At first the movements were

vigorous, *e.g.*, when held in the vertical position half an hour after death, all the swimming movements were repeated. At 1 hour and 40 minutes after death the muscles responded with the secondary coil at 15 cm., and they still responded 9 hours afterwards with the secondary coil at 0·0 cm. Soon after the irritability of the muscles was lost, rigor set in, and extended slowly backwards without producing very marked extension of the fins, and was completed about 19 hours after death. The rigor persisted unaltered for 11 hours, when it slowly vanished in the same order as it appeared, leaving the anterior two-thirds of the fish quite flexible about 36 hours after death, but remaining in the posterior third for nearly 7 hours longer. The temperature in both cases varied from 11° C. to 12° C.

When a somewhat exhausted roach was placed in water at a temperature of 35° C., the muscles rapidly lost their irritability and the rigor set in 30 minutes after death, was well established in 45 minutes, and was disappearing 2 hours after death, and quite off 2 hours 45 minutes after death.

At a temperature of 20° C. the rigor set in 1 hour and 30 minutes after death, and had all but passed off 4 hours after death. At a temperature of −1° C. the rigor came on extremely slowly. On placing several roach in water at a temperature of −1° C. and taking them out at intervals, I came to the conclusion that in small roach the rigor set in between 24 and 27 hours after death. In roach which had been in water at a temperature of −1° C. for 9 days, the rigor persisted for several hours after thawing, even when this was done very slowly. In the perch, generally speaking, the irritability of the muscles lasts longer the later the rigor is in appearing; *e.g.*, in a perch about 11 inches in length, which had been killed and pithed, the muscles were slightly irritable 13 hours after death, and the rigor was only fully established 9 hours later, and it had only disappeared from the anterior two-thirds of the fish 48 hours after death. But even a vigorous perch, if allowed to die in the usual way, may lose its muscular irritability and pass into rigor $2\frac{1}{2}$ hours after death, and become flexible again 16—18 hours after death, at a temperature of 11·5° C.

5. *The Disappearance of Rigor.*

It has long been admitted that there is some relation between the disappearance of rigor and the beginning of putrefaction, that in fact putrefaction assists in driving away the rigor. While endeavouring to discover a simple means for preserving fish in a fresh condition last autumn, it occurred to me that there might be a closer relation between rigor and putrefaction than had hitherto been determined, and that it might in fact be possible to prevent putrefaction by maintaining the post-mortem rigidity of the muscles   In order to ascer-

tain what ground there was for entertaining this notion, I proceeded to study the origin and nature of rigor in fish and other animals. At a very early stage I learned that the longer the rigor lasted the longer putrefaction was delayed, and also that putrefaction set in quicker in fish in which there was a large amount of putrescible matter in the alimentary canal, than in fish in which the alimentary canal was practically empty. For studying the relation of bacteria to the disappearance of rigor, I at the outset used sea fish, but afterwards trusted chiefly to fresh water forms, owing to the great difficulty in obtaining haddock and other fish in a perfectly vigorous condition. I soon observed that haddocks and whiting which were knocked on the head when captured (after the manner long practised by the fishermen who send "live" cod to Billingsgate) were longer in stiffening than fish which were left wriggling as long as their energy lasted in the hold of the boat. Later I found that the rigor persisted longer in haddocks and whiting which were gutted immediately after capture than in ungutted fish. If, *e.g.*, we take six haddocks (about the same size and captured on the same fishing bank at or about the same time) and, (1) leave two (Series A) to die in the usual way (temperature 7—8° C., (2) kill two (Series B) by knocking on the head and then pith, and (3) kill the other two (Series C) and both pith and gut; in Series A the rigor may appear 10 minutes after death, but in B and C it may not set in for 2 or 3 hours. Further, in A the rigor may have disappeared from the trunk (the portion co-extensive with the body-cavity) 10 hours after death, while in B it may persist for 13 hours, and in C for 20 hours, and while A might be quite limp 21 hours after death, B might continue rigid for 25 hours and C for 30 hours after death.

It may be taken for granted that rigor results chiefly from the formation and coagulation of myosin, and further, that the intensity of rigor depends on the amount of myosin formed in the various muscles. If nearly all the myosin-forming material has been used up before rigor appears in producing muscular contractions, comparatively little myosin will be formed, while in fish which have been pithed (if pithing diminishes the muscular contractions) there will be (except when the rigor is greatly delayed, as in the tail of the eel) sufficient material left to admit of a considerable amount of myosin appearing in the substance of the muscles.

But after all the amount of myosin formed in any given muscle accounts rather for the *firmness* of the muscle during the rigor than for the *duration* of the rigidity. Why does the myosin not continue unchanged? Why does it not, as it were, liquefy? And why does the rigor persist not only longer in some fish than in others, but also longer in some parts of individual fish than in others?

Experiments show that the rigidity is easily overcome (1) by alternate flexion and extension; (2) by raising the temperature; (3) by freezing; (4) by the action of acids and alkalies; and (5) by means of organisms. That this last cause is more important than all the others put together might, perhaps, be inferred from the fact that in fish in which bacteria abound in the tissues at death, either no rigor or a very weak one makes its appearance. This inference is confirmed by the following observations and experiments. (1.) A septic solution was injected into the right femoral artery of a newly killed rabbit, the rigor, though it appeared about the same time in the right limb as in the left, disappeared much quicker from the right. (2.) A large roach was killed on the 4th February and at once gutted. The muscles of the right side, immediately in contact with the peritoneal lining, were inoculated by septic bacteria (introduced by pricking the peritoneum with a rosette of needles fixed in a piece of sealing-wax) and the peritoneum covering the left side of the body-cavity was washed with a solution of corrosive sublimate (1 in 10,000). The rigor was to my surprise equally well marked on the two sides; but 24 hours after death, when the rigor began to disappear, the right side became limp about $2\frac{1}{2}$ hours before the left, and 36 hours after death the muscles of the right side were soft and beginning to putrefy, while those of the left were still firm; further, a piece of muscle taken from under the skin of the right side opposite the anterior margin of the dorsal fin swarmed with bacteria, while a piece of muscle from a corresponding point on the left side contained comparatively few bacteria. (3.) Roach and trout, which were gutted immediately after death, and dipped for a time in solutions of phenol (5 per cent.) and corrosive sublimate (1 in 1,000), and afterwards introduced into sterilised water, retained their rigor unimpaired for an indefinite time. Whenever the fish, however, were transferred from the sterilised into ordinary water, rigor began to disappear—the passing off being always accelerated when organisms were introduced into the water, or when the temperature was raised. Believing the rigor in the above fish might be mere stiffening produced and maintained by the action of the phenol and corrosive sublimate solutions, I introduced fish from which the rigor had been driven off by heat into similar solutions of phenol and corrosive sublimate. Limp fish treated in this way never became stiff—the natural firmness of the fresh muscles was simply maintained. (4.) Eels which were thrown into instantaneous rigor by strong electric shocks behaved in the same way. The posterior half of a large eel (the part behind the body-cavity) in cataleptic rigor was placed in phenol and then in sterilised water on the 8th April. A similar portion was introduced on the same day into sterilised water after the skin had been rendered aseptic by corrosive sublimate.

Both specimens are still (June 16th) in well marked rigor, and in the muscles near the cut surface I have been unable to detect any bacteria, and the reaction of the muscles is still slightly acid.

These and other experiments justify the conclusion that rigor, under ordinary circumstances, is in all probability driven away by putrefactive organisms. One of the most remarkable changes which accompanies the disappearance of rigor is the change of reaction of the muscles from acid to alkaline. As soon as the rigor begins to lose its hold the acidity diminishes, and gradually or rapidly disappears; for a time the muscles are neutral, but sooner or later they are distinctly alkaline. The muscles around the body-cavity become alkaline first, from these muscles the alkalinity extends outwards towards the skin, and later extends into the muscles of the tail, but in some cases a long interval elapses between the appearance of the alkaline reaction in the sub-peritoneal muscles and the myotomes situated behind the body-cavity. A point of considerable interest is that the reaction of the muscles under the skin passes from acid to alkaline before they are invaded by bacteria. This can be readily proved by introducing into a culture-medium a fragment of muscle from under the skin of the trunk from which the rigor has just gone, and which is already faintly alkaline, and as a test experiment a similar fragment from under the peritoneum from a point as nearly as possible opposite where the first was taken. In the latter case bacteria rapidly appear, while no bacteria (if all the necessary conditions have been observed) will appear in the former. By a series of experiments I have proved that while weak solutions of hydrochloric and sulphuric acids are incapable of preventing the putrefaction of fish, they have the power of arresting or at least greatly retarding the development of ordinary bacteria. Seeing that the alkaline wave radiates from around the body-cavity in advance of the bacteria, it is extremely likely that the one results from the presence of the other. In fact we may, until further experiments have been made, suppose that rigor disappears in the presence of a species of fermentation, that the bacteria which reach the tissues from the body-cavity manufacture ferment-like substances, which as they diffuse through the muscles drive the rigor before them, adapting the tissues on the way for the suitable reception and nourishment of a crop of putrefactive bacteria in much the same way as the husbandman breaks up and otherwise prepares the soil before sowing his corn. In all probability the duration of the rigor partly depends on the readiness with which the tissues can be made alkaline, and partly on the amount of mechanical obstruction the bacteria have to overcome in the muscular fibres. It is well known that gelatine and other culture-media, when slightly acid, or when too much dried, are rendered for a time altogether unsuitable for the cultivation of

certain bacteria. In the same way the muscles of certain fish, either because of their peculiar chemical composition, or because of the peculiar disposition and structure of the tissues composing them, lend themselves less readily than the muscles of others to the invasion of the putrefactive organisms. It is well known that at even comparatively low temperatures fish rapidly putrefy when the atmosphere is loaded with moisture, and that when the atmosphere is dry even at fairly high temperatures putrefaction is comparatively slow, and as dried gelatine is protected from the attacks of most organisms, by drying fish putrefaction is arrested generally in ratio to the completeness of the desiccation.

It is scarcely necessary to point out the practical bearing of this inquiry.

In fish putrefaction, when it once sets in, proceeds much more rapidly than in other vertebrates. This being the case, fish should be used as soon as possible after the rigor disappears. Inspectors of fish markets and fish dealers have various empirical tests by which they believe they are able to determine whether fish are or are not fit for food. They especially trust to the colour of the gills, the firmness and colour of the muscles, and the nature of the odour. As a matter of fact, it is often almost impossible to say whether a fish is or is not fresh after the rigor has disappeared. There is often a pause in the putrefactive process (caused probably by the first crop of bacteria being destroyed by their own bye-products). For this reason it is desirable fish should be used as soon as possible after the rigor has vanished, and that fish, intended for preservation (it matters little how), should be treated, if possible, while the rigor lasts.

I have made numerous experiments with ice for preserving fish. It is generally alleged that fish which have been preserved for some time in a frozen state have lost much of their flavour. This I find depends partly on when the freezing is effected and partly on the temperature maintained. Fish which are frozen after the rigor has gone have either very little flavour or they are tainted with offensive septic products. But fish which have been frozen *before* rigor sets in (which have probably never stiffened) are equally without flavour, and they rapidly soften and disintegrate when raised to ordinary temperatures. On the other hand, fish which are frozen immediately after the rigor sets in remain almost unaltered, and when cooked can scarcely be distinguished from fresh fish unless the temperature has been unnecessarily low. The most perfect results were obtained by keeping fish (both salt and fresh water) at a temperature varying from $-1°$ to $-2°$ C. Haddocks which were pithed and gutted and preserved in water-tight insulated chambers at a temperature of $-2°$ C. for three weeks continued rigid from first to last, and when cooked were firmer and better flavoured than ungutted fish only ten hours out

of the water. For some reason not easily understood, the fish preserved in water at $-1°$ C. were firmer and better in every way than fish at the same temperature in boxes from which the water escaped as the ice melted. Fish intended for drying and pickling, *i.e.*, for preserving for a long period, should also be treated before or as soon as possible after the rigor goes.   When a fish has once begun to disintegrate it is impossible to restore the original freshness, and unless all the flavours are destroyed during the preserving process the results of previous decomposition can easily be detected.   Some fish, as curers well know, are incapable of being preserved even with salt, *e.g.*, fish which have died struggling in the water entangled in gill nets are difficult to preserve, because under these conditions, as experiments prove (probably in consequence of the acid reaction thus determined), no distinct rigor ever sets in—death being at once followed by putrefactive changes.

Fish hitherto have usually either been lightly salted and sun-dried, or after being saturated with salt pickled in strong brine. A 20 per cent. salt solution almost completely alters the tissues. Apparently salt owes its preserving power to the fact that it arrests (though it fails to destroy) putrefactive organisms by a process of desiccation—extracting the fluids, without which growth is impossible.

Unfortunately we are acquainted with extremely few substances able in small quantities to arrest the growth of bacteria without rendering the fish unfit for food. It is extremely desirable to at least greatly diminish the amount of salt required. This has recently been rendered possible by a process introduced by Mr. Sahlstrom of the Normal Company. In this process the fish are introduced into a cylinder, and, after all the air has been removed by pumping, pressure (5 to 6 atmospheres) is applied to drive the preservative solution (which may contain salt alone, or salt along with other preserving reagents) into the tissues. I have made an extensive series of experiments by this method, and in all cases when fish in a rigid condition were treated, succeeded in arresting putrefactive changes, either permanently or for a limited period according to the strength of the solution used.

This inquiry throws some light on another question which has long been discussed, viz., whether line-caught fish are preferable to fish taken by the beam trawl. In order finally to settle this question, it is only necessary to ascertain whether the rigor disappears quicker in the one case than in the other. I have already mentioned that a line-caught haddock, which has been killed and pithed the moment it leaves the water, may at a temperature of $8°$ C. remain stiff for 30 hours, *i.e.*, putrefaction may be retarded from 25—30 hours. On the other hand haddocks, captured by a 25-feet beam trawl which had only been two hours at work (large trawls are often down for six hours), even when

killed and pithed immediately after taken from the net, may pass into rigor in 30 minutes and be again quite limp 6 hours after death. Sometimes, however, the rigor may not set in for 2 hours after the fish are landed, and it may continue for 17 hours, the difference doubtless resulting partly from the difference in the time the fish were in the trawl net, and partly from the energy expended in attempting to escape, or in endeavouring to maintain the respiratory movements under somewhat difficult circumstances. It may therefore be affirmed that though the rigor may persist as long or nearly as long in some trawled fish as in fish caught with a line, in most cases the rigor disappears sooner from trawled than from line-caught fish; in other words, putrefaction sets in sooner as a rule in fish taken by the trawl than in fish taken by the line, granting, of course, that the line fish are pithed and gutted as soon as they leave the water.

I have, in conclusion, to express my gratitude to Professor Burdon Sanderson and Mr. Gotch for valuable assistance rendered with the experiments made in the Oxford Physiological Laboratory. I am also indebted to Professor Tait for kindly allowing Mr. Lindsay, of the Natural Philosophy Laboratory in the University of Edinburgh, to assist with the electrical experiments. I am further indebted to Mr. Clarkson, B.Sc., of the Natural History Department, Edinburgh, and Mr. W. L. Calderwood and Mr. Jamieson, Members of the Staff of the Fishery Board for Scotland.

XXVI. " Electrochemical Effects on Magnetising Iron." By Thomas Andrews, F.R.S.E., F.C.S. Communicated by Professor G. G. Stokes, P.R.S. Received June 2, 1887.

Having for many years past been engaged in researches relating to the various aspects of the corrosion and oxidation of metals, nearly two years ago it occurred to me to investigate the probable effect of magnetisation on the relative electrochemical position of a pair of bright iron bars, one magnetised by a coil, the other unmagnetised, when thus simultaneously exposed in circuit, in a suitable apparatus, to the action of various powerful oxidising agents and saline solutions. I accordingly specially prepared numerous long polished rods of soft wrought scrap iron 0·261 inch diameter, for use in the investigation. I was not able to commence the preliminary observations until towards the end of 1885, and, after much consideration and various trials then made, decided to adopt the following method of experimentation as perhaps calculated to yield the most delicate and accurate results; pressure of other work has, however, delayed the earlier completion of the work. The general